National Aeronautics and Space Administration

Revolutionary Vertical Lift Technology Status Update

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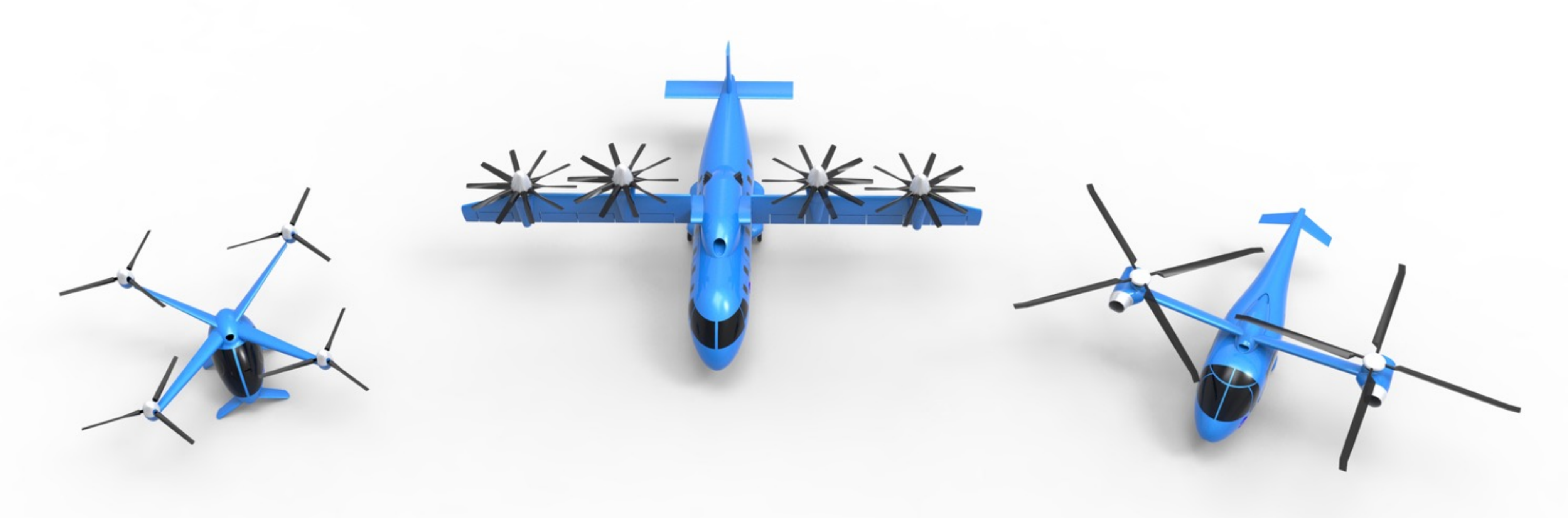
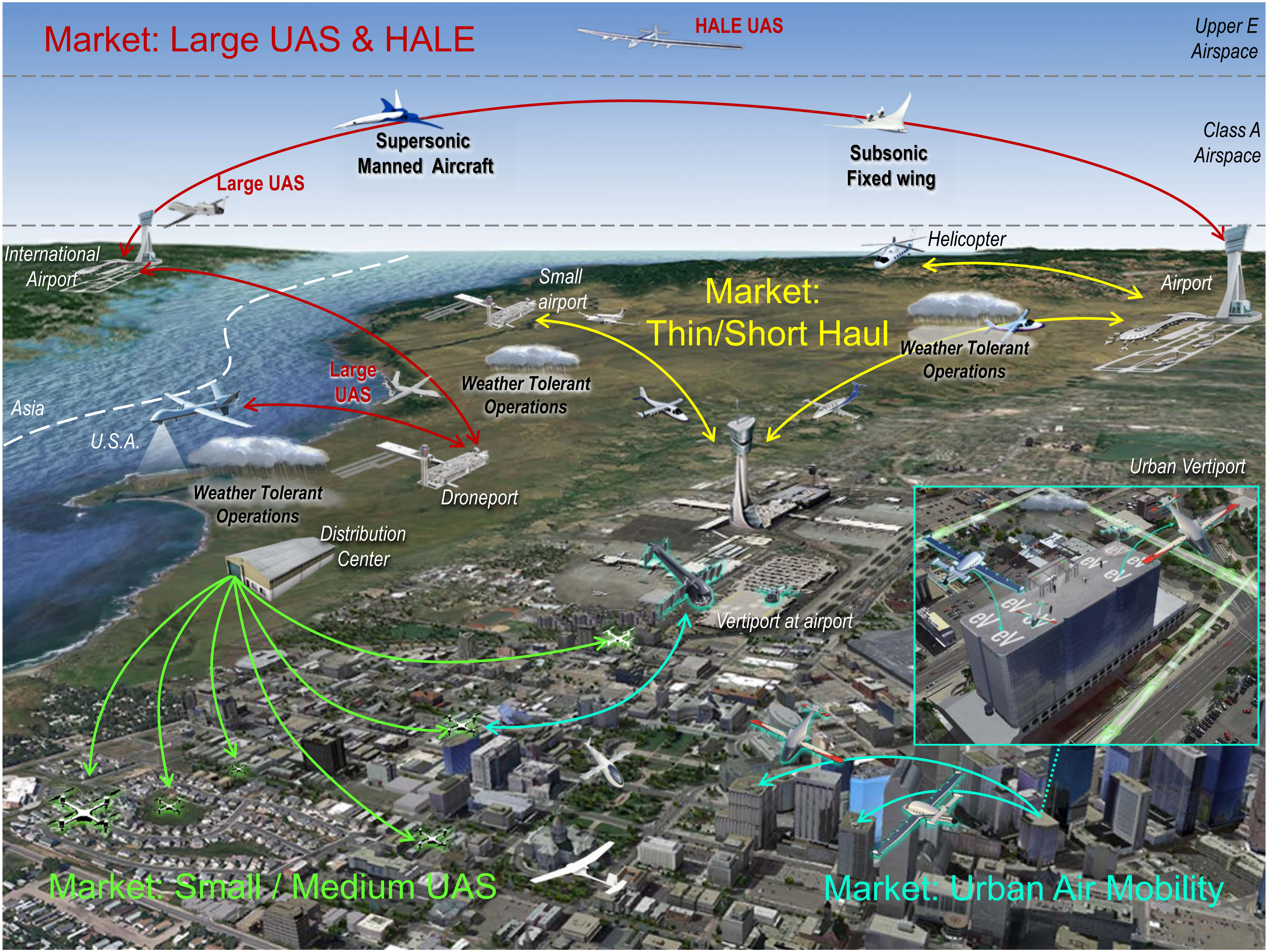
August 2018

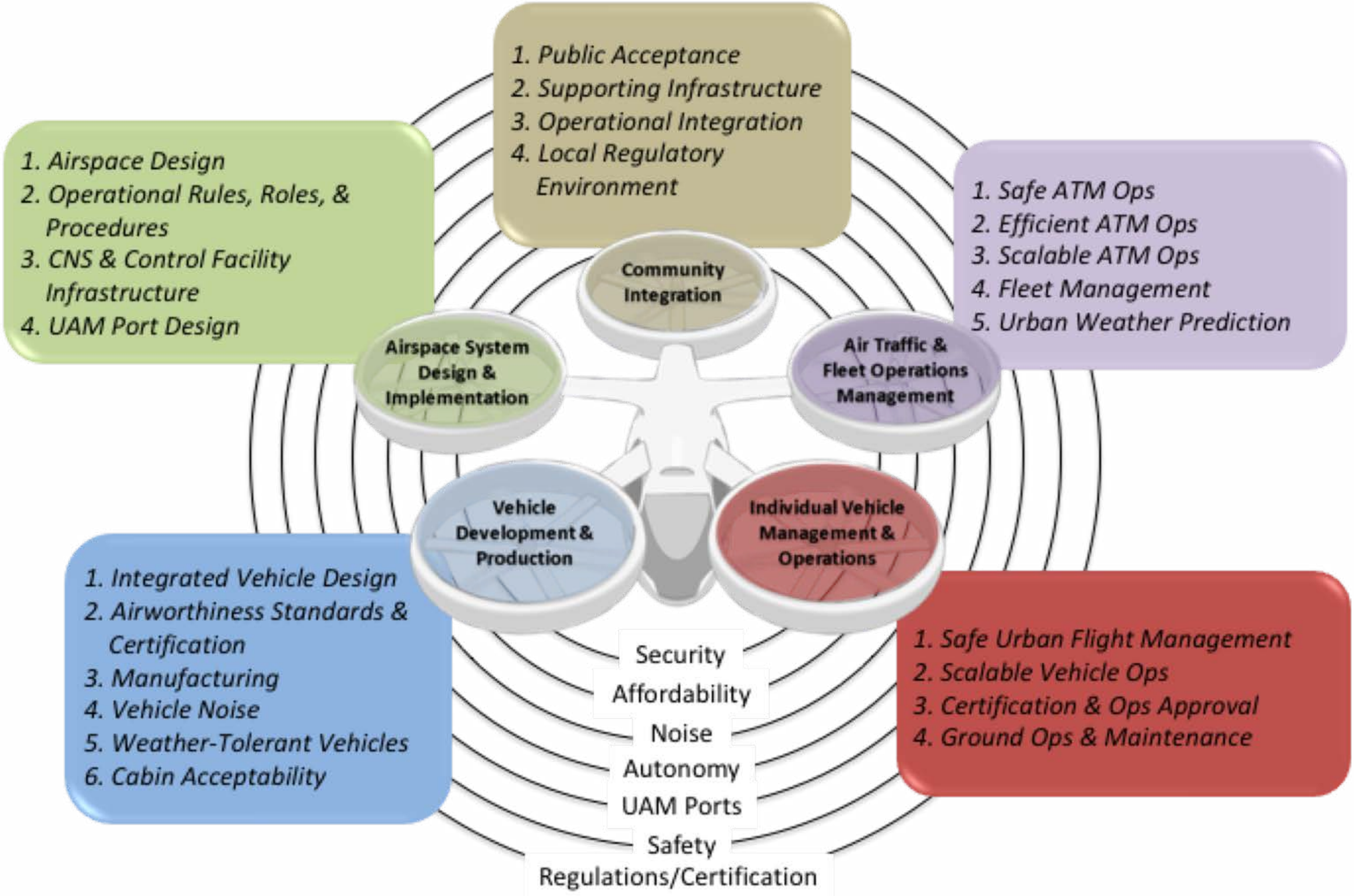
RVLT Progress FY18

- Connecting to the SIP, new Thrusts, and UCAT
- What RVLT is hearing in the community
- RVLT Concept Vehicles and research areas
- RVLT resources, structure, housekeeping
- Highlights from FY18
- Priorities for FY19
- Summary




Market: Large UAS & HALE
HALE UAS
Upper E
Airspace
Supersonic
Manned Aircraft
Subsonic
Fixed wing
Class A
Airspace
Large UAS
International
Airport
Helicopter
Small
airport
Market:
Thin/Short Haul
Airport
Weather Tolerant
Operations
Large
UAS
Weather Tolerant
Operations
Asia
U.S.A.
Weather Tolerant
Operations
Droneport
Urban Vertiport
Distribution
Center
Vertiport at airport
Market: Small / Medium UAS
Market: Urban Air Mobility

UCAT: UAM Framework with Barriers and Cross-Cutting Considerations



Hearing a Broad Spectrum of Ideas

- Market/ mission (personal transport—EMS—air taxi—intercity--intracity—cargo)
- Mission range (25-400nm)
- Aircraft configuration (pure rotors, compound vehicles, lift+cruise, tilt concepts, vectored thrust, circulation control)
- Propulsion concepts (all-electric, hybrid-electric, battery for emergency only, turbo-electric)

Even for the same market/mission, there are different approaches throughout the industry. There is no agreement on "best" vehicle type or approach and no standards (performance, cost, safety) for comparison.

NASA-developed Concept Vehicles for UAM

Objective: Identify NASA vehicles to serve as references to openly discuss technology challenges common to multiple concepts in the UAM community and provide focus for trade studies and system analysis

Passengers	50 nm trips per full charge/ refuel	Market	Type	Propulsion
1	1 x 50 nm	Air Taxi	Multicopter	Battery
	2 x 37.5 nm			
2	2 x 50 nm	Commuter Scheduled	Side by Side (no tilt)	Parallel hybrid
4	4 x 50 nm	Mass Transit	(multi-) Tilt wing	Turboelectric
6	8 x 50 nm	Air Line	(multi-) Tilt rotor	Turboshaft
15			Lift + cruise	Hydrogen fuel cell

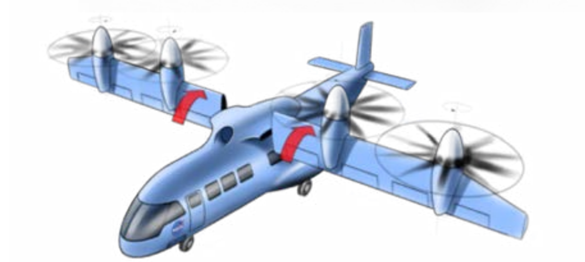
- Aircraft designed through use of NASA conceptual design and sizing tool for vertical lift, NDARC.
- Concepts described in detail in publications "Concept Vehicles for Air Taxi Operations," by Johnson, Silva and Solis. AHS Aeromechanics Design for Transformative Vertical Lift, San Francisco, Jan. 2018 and "VTOL Urban Air Mobility Concept Vehicles for Technology Development," by Silva, Johnson, Antcliff and Patterson. AIAA Aviation 2018, Atlanta, GA, June 2018.

Quadrotor "Air Taxi"

Side by Side "Vanpool"

Lift+Cruise Air Taxi

Tilt wing "Airliner"



Research Areas Applicable to All Concept Vehicles

PROPULSION EFFICIENCY

high power, lightweight battery
light, efficient, high-speed electric motors
power electronics and thermal management
light, efficient diesel engine
light, efficient small turboshaft
efficient powertrains

PERFORMANCE

aircraft optimization
rotor shape optimization
hub and support drag minimization
airframe drag minimization

ROTOR-ROTOR INTERACTIONS

performance, vibration, handling qualities
aircraft arrangement
vibration and load alleviation

Quadrotor + Electric

Tiltwing + TurboElectric

Side-by-side + Hybrid

Lift+Cruise + TurboElectric

ROTOR-WING INTERACTIONS

conversion/transition
interactional aerodynamics
flow control

SAFETY and AIRWORTHINESS

FMECA (failure mode, effects, and criticality analysis)
component reliability and life cycle
crashworthiness
propulsion system failures
high voltage operational safety

STRUCTURE AND AEROELASTICITY

structurally efficient wing and rotor support
rotor/airframe stability
crashworthiness
durability and damage tolerance
high-cycle fatigue

OPERATIONAL EFFECTIVENESS

disturbance rejection (control bandwidth, control design)
all-weather capability
passenger acceptance/ ride quality
cost (purchase, maintenance, DOC)

NOISE AND ANNOYANCE

low tip speed
rotor shape optimization
flight operations for low noise
aircraft arrangement/ interactions
cumulative noise impacts from fleet ops
active noise control
cabin noise
metrics and requirements

AIRCRAFT DESIGN

weight, vibration
handling qualities
active control

Red = primary focus
Blue = secondary focus

NASA RVLT Project Research Areas, FY19

Ames Research Center

- Aeromechanics
- System Analysis
- Computational Methods
- Experimental Capability
- Flt Dyn & Ctrl
- Acoustics

Glenn Research Center

- Hybrid/ Electric Systems
- Electro-Mech Powertrains
- Small Turboshaft Engines
- Icing
- System Analysis
- Impact Dynamics
- Acoustics

Langley Research Center

- Acoustics
- Computational Methods
- Aeromechanics
- Experimental Capability
- Impact Dynamics
- System Analysis

- *Typical NASA research is TRL 1-5, sometimes 6*
- *Typical NASA products are feasibility studies, technology demonstrations, research reports*
- *Partnerships enable faster technology transition to DoD and industry*

Resources and Facilities

<u>FY18 RVLT Summary</u>

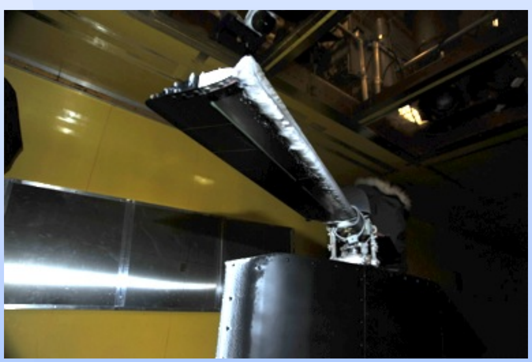
~74 Civil Service Workforce
~ $23.4M per year
(includes salary)

Ames Research Center

- National Full-Scale Aerodynamics Complex (NFAC)
- Supercomputing Complex (NAS)
- Vertical Motion Simulator

Glenn Research Center

- Compressor Test Facility (CE-18)
- Transonic Turbine Blade Cascade Facility (CW-22)
- Transmission Test Facilities (ERB)
- Icing Research Tunnel



Langley Research Center

- 14- by 22-Foot Subsonic Tunnel
- Transonic Dynamics Tunnel
- Landing and Impact Research
- Mobile Acoustic Facility
- Low-Speed Aero-acoustic Wind Tunnel

- Exterior Effects Synthesis & Sim Lab

FY18 Progress and News

- Reference configurations (previous charts)
- Tiltrotor Test Rig
- MDAO Tech Challenge
- Acoustic Flight Test
- Fly Neighborly
- Electric Propulsion Planning
- Transition Testing in 14- by 22-Foot Subsonic Tunnel
- Other highlights
- Mars Helicopter

Tiltrotor Test Rig (TTR)

Objective

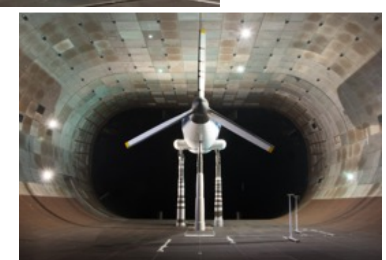
– Recover ability to conduct large-scale tiltrotor experimental research

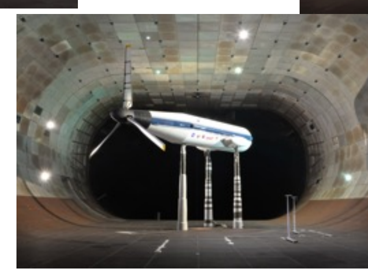
Approach

– Design, fabricate and qualify new tiltrotor test rig to test proprotors up to 26-ft diameter in the National Full-Scale Aerodynamics Complex (NFAC) in axial mode, transition, and edgewise flight
– Completed balance calibration, instrumentation installation, and motor/gearbox checks
– Conduct functional checkout of complete system in the NFAC. First run with blades spinning June 9, 2017.
– Completed hover runs, March 2018
– Planned forward flight testing, Aug 2018

Significance

– TTR is a new national facility asset that will enable advanced, large-scale tiltrotor technology testing at speeds up to 300 knots. TTR provides a unique test bed for NASA, DOD and industry research for high-speed configurations.





Partners: Army ADD, Air Force; Prime Contractor: Bell Helicopter Textron

Completed L2 Milestone: VTOL Configurations Optimized for Low Environmental Impact (Emission and Noise)

PROBLEM Can an optimization process be developed to design vehicles with lower emissions and substantially lower noise than corresponding baseline vehicles?

OBJECTIVE Reduce the noise of one or more of the low-emission vehicles designed under Phase 1: Designs Optimized for Low Emission.

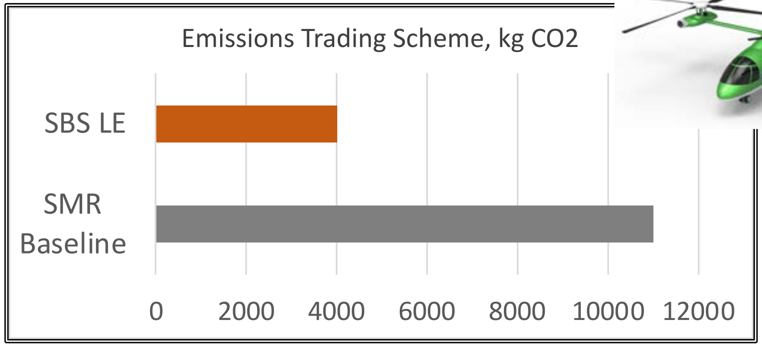
APPROACH Combine the processes/results from the 3 milestones to optimize the rotor geometry of one or more of the low-emission vehicles.

ACCOMPLISHMENTS Using a sequential optimization process, SBS LE vehicle was designed and had 60% lower emissions compared to a baseline SMR vehicle.

- SBS LE did not meet FAA Stage 3 noise requirements on approach. A toolchain was used to optimize the dihedral of the rotor blade tips of the SBS LE such that it met the descent level limit.
- When the SBS LE with tip dihedral optimized for reduced noise is compared to the baseline SMR for the FAA noise certification descent condition a reduction of 9.6 EPNdB (or 67%) is achieved.
- A tip (r/R > 0.6) dihedral of -40 deg gave the largest noise reduction.

SIGNIFICANCE A process for optimizing the emissions and noise reduction of conceptual design vehicles has been established. Future efforts will focus on streamlining the work flows and exploring simultaneous optimization of emissions and noise.

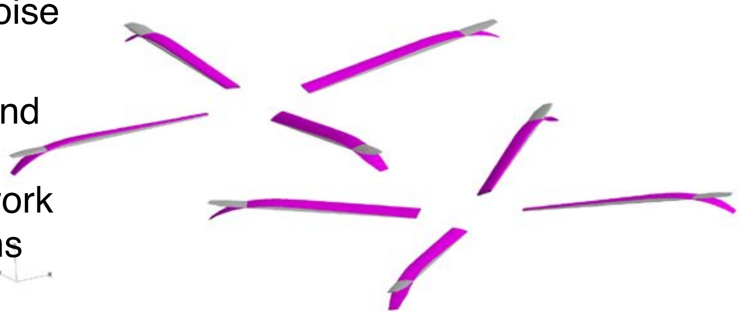
Design optimization for low emission



Comparison of predicted noise metrics[1] for FAA descent condition required for noise certification

Vehicle	ETS[2]	Average EPNdB
Baseline SMR[3]	11,000	100.8
Baseline SMR with an optimized rotor	11,000	89.0
SBS LE[4]	4000	106.8
SBS LE[4] with an optimized rotor	**4000**	**91.2**

Optimized system has both emission improvement of 63% and acoustic improvement of 67% over baseline.



[1] average of three microphones located per FAA noise certification for helicopters
[2] Emissions Trading Scheme, kg CO_2
[3] SMR: single main rotor
[4] SBS LE: side-by-side, low emission

Rev.: 5/8/2018

NASA-FAA-Army Low Noise Operations Flight Test Completed

OBJECTIVES:
1. Obtain data to help identify low noise maneuvering techniques and corresponding flight procedures.
2. Obtain source noise for aircraft modeling tools

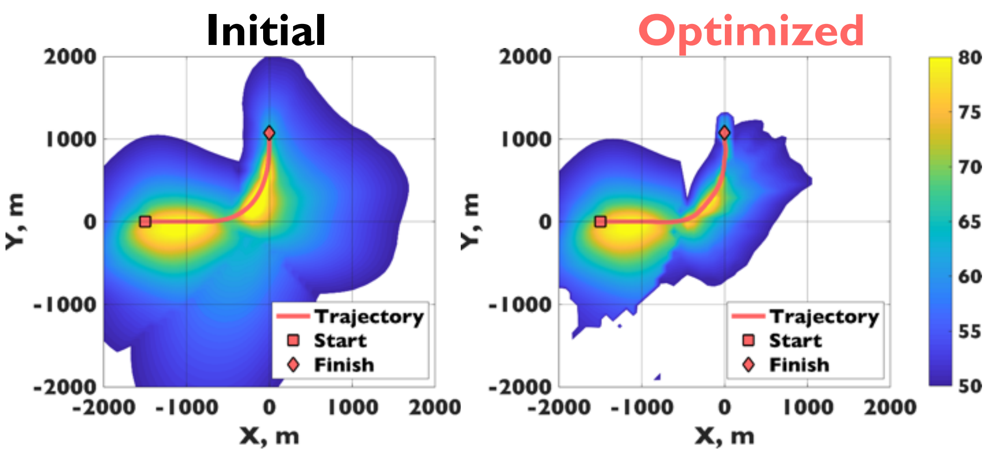
APPROACH:
Developed low noise flight procedures to minimize the impact of helicopter operations. NASA and the FAA tested 6 helicopters in order to develop general "rules of thumb" for low noise flight procedures.

ACCOMPLISHMENTS:
- R-44 and R-66 were tested at Eglin AFB in both steady and dynamic flight conditions with all priority points acquired.
- Bell 207L, Bell 407, AS350, EC130H were tested at Amedee Airfield with all priority points acquired.

SIGNIFICANCE:
Analysis of configurations and flight operations have resulted in generalizations for low noise trajectories. These will be incorporated into the Fly Neighborly information and upcoming workshops.

The data will be used to calibrate NASA tools and contribute to the development of real-time acoustic information as a cockpit display.

Optimized Flight Trajectories



Partners: FAA, Army

Fly Neighborly

NASA flight acoustics research being used by owners and operators

Fly Neighborly

Noise Abatement Recommendations

Level Flight:

- Accelerations are quieter than decelerations
- Straight flight is quieter than turns

Turning Flight:

- Turn away from the advancing blade, especially if you are decelerating
- Level turns are quieter than descending turns

Descending Flight:

- Straight-in flight is quieter than turns
- Fly the steepest angle practicable to reduce the noise footprint

Decelerations:

- Level segments are quieter than approaches or turns

Maneuvering:

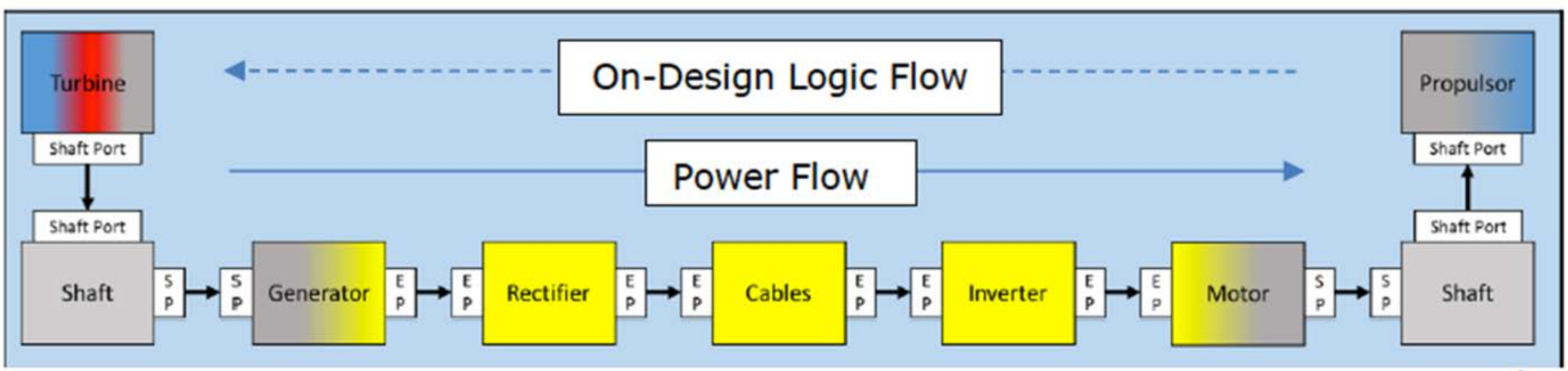
- Make smooth control inputs to reduce the noise footprint

These recommendations are flight tested and scientifically vetted by the U.S. Department of Transportation Volpe Center and NASA. Take the Fly Neighborly training at: https://www.faasafety.gov/gslac/ALC/course_content.aspx?pf=1&preview=true&cID=500

RVLT Approach for Electric Propulsion

Objective: Develop guidelines for life, safety and performance of UAM VTOL electric propulsion systems to feed certification requirements

RVLT will
- Assess critical components and failure modes across four concept vehicles
- Define requirements to mitigate hazards - design, operations and service life
- Assess tools & technologies for long-life, fault tolerant propulsion systems
- Develop test capabilities & perform experiments to demonstrate tools and technologies for long-life, fault tolerant propulsions systems
- Create design guidelines and tools for propulsion components in coordination for safe, long-life propulsion system designs



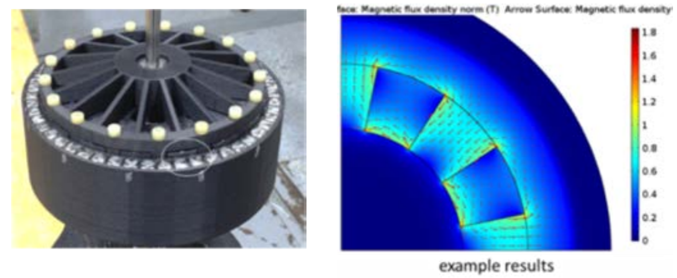
NASA developed electrical ports in Numerical Propulsion System Simulation (NPSS) under RVLT sponsorship

Highlights of Research Activities (1)

Advanced drives: Demonstrated three novel devices: 1) Piezoelectric based and magnetorestrictive based “vibration rings “ devised to prevent transfer of vibration energy to aircraft cabins; 2) Magnetorestrictive based “vari-stack” has achieved high frequency switching of mechanical stiffness as a means of vibration isolation; 3) magnetically-geared prototype for shaft speed reduction and torque multiplication with no contacting gear teeth

Compressor research: Completed the testing of the vaneless diffuser in FY18. Over 2000 steady state data points were collected, and approximately 150 unsteady data points were collected.

Hover test preparation: Design and fabrication of new small-scale pressure-instrumented blade underway. Hardware buildup of the Army Rotor Test Stand (ARTS) was completed and additional parts and components are being purchased and assembled.



magnetic gearing prototype and magnetic flux analysis


Vaneless diffuser component


ARTS

RVLT Big Picture Priorities for FY19

- Clean and Efficient Propulsion
  - Incorporate Failure Modes, Effects, Criticality Analysis (FMECA) contract results into research plan
  - Establish requirements for electric propulsion test facilities; assess needs and gaps
  - Approval of Tech Challenge for Electric Propulsion
- Efficient and Quiet Vehicles
  - Complete TC3.1 for Low Noise Rotor Systems by end of FY19
  - Complete FY19 API based on TC3.1 (LaRC lead)
  - Approval of Tech Challenge for UAM Fleet Noise
- Safety, Comfort, Affordability
  - Plan for handling qualities/ ride quality simulation for Urban Air Mobility
- ModSim and Test
  - Complete TC2.1 for conceptual design by end of FY18
  - Increase capability for system trades and technology evaluation for urban air mobility
  - Approval of Tech Challenge for UAM Design and Analysis Tools

UCAT

TTT/ MDAO and other

TTT/ Autonomy research

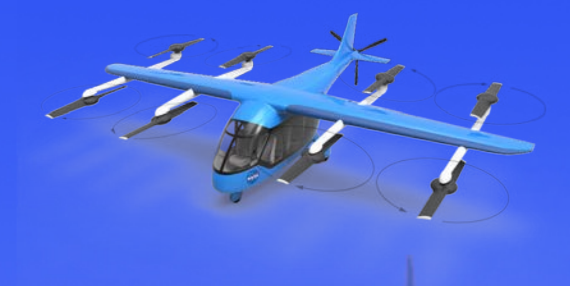
ATM-X collaboration

FDC coordination

Summary

NASA RVLT is focused on

- Overcoming significant barriers to the use of vertical lift vehicles in expanded missions
- Providing technology leadership
  - Technologies and tools to enable low noise design and operations and reduce annoyance
  - Tools, data and methods to enable safe, efficient electric propulsion systems
  - Technologies and concepts that improve safety, mobility, payload and speed



- Developing vision of the future for vertical lift; identifying technical challenges for new markets
  - Methods to assess advanced innovative concepts
  - Pathfinder for next gen market technologies